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Critical Diameter Study of Unconfined
Australian Manufactured Composition B,
Grades A and B

R.J. Swinton and L. McVay

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ABSTRACT

Composition B is a widely used high explosive main charge filling for general purpose bombs. In Australia it is manufactured from either RDX (Grade A or Grade B)/TNT 60/40 with 1% wax, or RDX (Grade B)/TNT 55/45 with 1% wax.

In weapon applications computational models require experimental data to determine certain specific output parameters of Composition B to predict air-blast and fragmentation scenarios. To this end, the critical diameter, which is the minimum diameter which will sustain a stable detonation, and the limiting value of the velocity of detonation at infinite charge diameter $D(\infty)$, were determined for unconfined cylinders of each Composition B type. An ionisation probe technique was used to measure the velocity of detonation (V of D) of the samples over a range of charge diameters (d).

The data thus obtained was fitted to an elliptical V (d) relationship to obtain the critical detonation parameters below:-

RESULT				
Parameter	**Symbol**	**Composition B RDX type**		
		Grade A 60/40/1	**Grade B 60/40/1**	**Grade B 55/45/1**
V of D at infinite charge diameter	D_∞	7723 m/s	7658m/s	7659 m/s
cut-off velocity	$V(d_c)$	6883 m/s	6836 m/s	6831 m/s
reaction zone length	a^*	3.04 mm	0.86	1.64
critical diameter	d_c	6.7 mm	1.9 mm	3.6 mm

Although separate experiments suggested a trend of shock sensitivity decreasing with RDX particle size insufficient data was available to investigate the observations.

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Executive Summary

Computational models for predicting air-blast and fragmentation performance of warheads (general purpose bombs, shells, mines and missiles) require input data for the detonation parameters of the explosive fillings. The most widely used of these fillings in the ADF inventory is Composition B, which is the melt-cast blend of RDX/TNT commonly in the proportions 60/40 with 1% added Beeswax.

Up until 1977 there were two distinct grades of RDX manufactured in Australia :-
(i) fine grained milled and boiled (M&B) RDX (average particle size ~ 75 μm) and
(ii) coarse grained recrystallised (R_x) RDX (with an average particle size of ~ 170μm)

On experiencing difficulties loading shells with the 60/40/1 Composition B blend of the fine grained M&B type RDX the filling factories, on AMRL's advice, changed the blend to 55/45 RDX/TNT with 1% added Beeswax. This meant that Australian Composition B munitions could have any of the following three variant fillings:-

60/40/1 RDX/TNT/Wax from R_x RDX crystals
55/45/1   "   "   "   from M&B RDX crystals, and least commonly
60/40/1 RDX/TNT/Wax from M&B RDX crystals

Strategic stocks of the no longer produced M&B variant are currently being run down and replaced by the more favoured R_x variant.

Much to the frustration of analysts experimenting with Composition B, quantitative results sometimes appearred to contradict each other, which brought doubt to mind about what specific Composition B had been tested. The investigation addressed this problem by determining the following critical explosive parameters to characterise the three Composition B formulations;
   velocity of detonation at infinite charge diameter, $D(\infty)$
        the critical diameter, d_c
        the cut-off velocity, $V(d_c)$
     and the reaction zone , a^*.
These data are important in defining the detonation behaviour of Composition B and should prove useful in elucidating the mechanism that occurs at the threshold of detonation. Importantly the data provides a range of input parameters required by AMRL computational models for predicting munition warhead performance and associated target vulnerability in support of ADF weapon systems. Therefore, the outcomes from this study will enhance DSTO`s capability to provide smart buyer value and operational performance assessment for Composition B filled weapon warheads.

Authors

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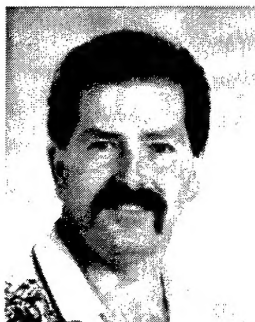
Bob Swinton graduated Diploma of Applied Chemistry from Footscray Institute of Technology in 1978 and Certificate of Occupational Health and Safety from Kangan Institute of TAFE in 1996. He joined Explosives Division MRL in 1967 and has specialized in explosives analysis and testing, sensitivity and hazards assessment and device development. He is currently working on explosives terminal effects.

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Contents

1. Introduction

Several variants of Composition B have been produced and used in Australia over the years, principally due to improvements in the fabrication process. Studies with the materials have shown that the Composition B variants exhibit different explosive properties eg. small scale and large scale shock sensitivity [1,2]. A knowledge of an explosives properties is a fundamental requirement in predicting weapon performance, modelling its behaviour and understanding its initiation and detonation mechanisms.

This report describes the results of a study which determined the steady state detonation parameters of Australian Composition B variants and makes some observations on the dependence of these parameters on the variations in the explosive compositions. Among the parameters determined for each composition were:

(i) the critical diameter d_c, which is the minimum diameter which will sustain a stable detonation,

(ii) the limiting value of velocity of detonation at infinite charge diameter, D_∞, and

(iii) the minimum cut-off or threshold velocity $V(d_c)$.

By applying Whelan's [3a, b] recently published elliptical relationship between the experimentally determined V of D of unconfined cylindrical charges of the compositions and the charge diameter (d), a curve fitting constant a* could be calculated. This allowed the d_c, D_∞, and $V(d_c)$ to be determined.

1.1 Composition B, Designation and Background

Composition B is the common name for the widely used high explosive shell and bomb filling which is a melt-cast blend of RDX (cyclotrimethylenetrinitramine) and TNT (trinitrotoluene). Typically, Composition B consists of RDX (59.5 %, by mass), TNT (39.5 %) and Desensitising Wax (1%). However, its properties vary somewhat depending on the actual formulation studied and the purity and class of its ingredients.

The RDX component of Australian Composition B up till ca.1986 was manufactured at Albion Explosives Factory (AEF) by the Woolwich process (direct nitration of hexamine) and, unlike its American counterpart, this Woolwich type RDX is free of HMX [4]. Up until 1979, the manufacturing process of RDX at Albion included, at the penultimate stage of production, a milling and boiling step, which was designed to break down crystalline aggregates and remove traces of residual acid [5]. This RDX was designated **Grade B, Class 1.**

In the 1960's, however, the various Australian Explosive Filling Factories reported that they were experiencing difficulty in casting Composition B (RDX/TNT 60/40 with 1% wax) with milled and boiled RDX and it was demonstrated subsequently that this arose because of the presence of excessive quantities of "fines" in the RDX; these "fines" increased the viscosity of the resulting Composition B mix until it became almost unpourable [6]. On the other hand, when coarser grained RDX (for instance that from the Royal Ordnance Factory, Bridgewater, Somerset, UK) was used to produce Composition B, the pouring problem no longer occurred. The UK-produced RDX material had been recrystallised from cyclohexanone and had a distinctly different particle size distribution .

Accordingly, in 1977, (AEF) decided to introduce a recrystallisation from cyclohexanone as the final step in its RDX manufacture and this material was designated **RDX Grade A, Class 1 (Type 1)**. The Grade and Class refer to the particle size distribution of the RDX, the Type refers to the chemical manufacturing process (Woolwich, Type 1 or Bachman, Type 2). For simplification the symbol R_x has been used in this report to describe the above RDX, and M&B to describe the milled and boiled Grade B RDX.

An interim measure, which allowed for the reduction of strategic stocks, created the situation of the munitions filling factories producing pourable castings from M&B RDX by reduction of the RDX content. As a consequence of the evolving development and use of Composition B in Australia the following variants have been most commonly used in munition fills and R&D studies :

Table 1. Composition B variants commonly used in Australia

RDX (type)	RDX %	TNT %	Wax	Composition B Designation
R_x	60	40	1% added	R_X variant
M&B	55	45	1% added	M&B1 variant
M&B	60	40	1% added	M&B2 variant

This report covers a study of the above three Composition B variants with the aim of :

(a) establishing their d_c
(b) evaluating how the physical form of the RDX used, changes the Composition B performance characteristics .
(c) comparing the results thus obtained with those reported from US laboratories [7, 8], and
(d) rationalising the results in the light of the reported differences in gap test shock sensitivities between the variants.
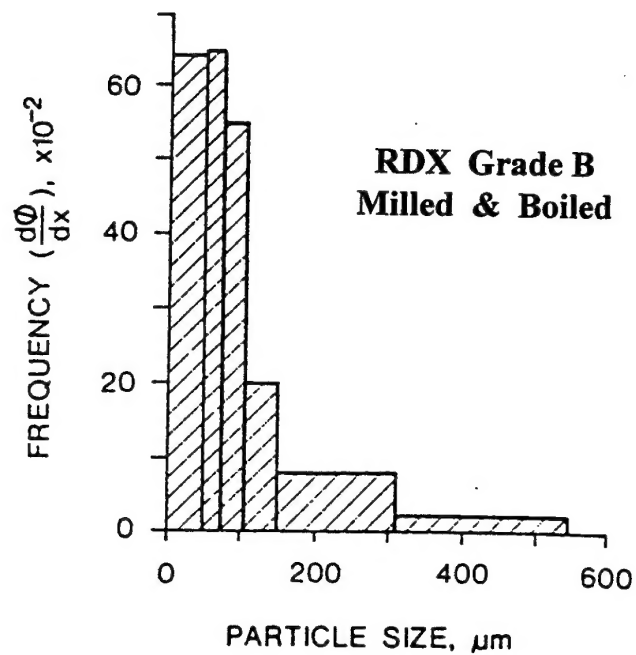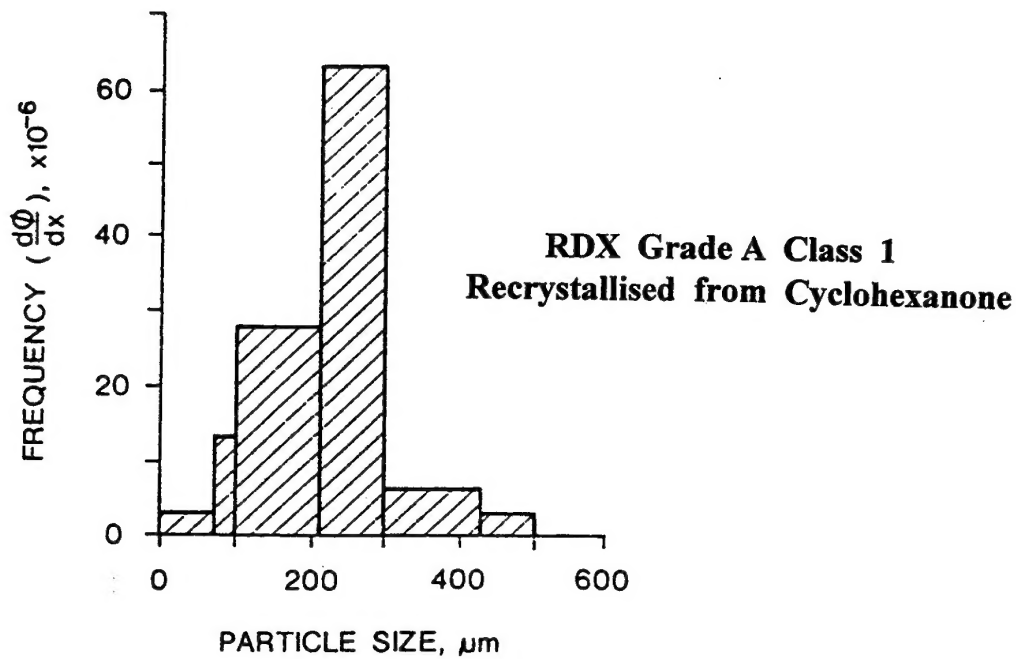
Figure 1. *Histogram of particle size distribution measured using a Malvern Particle Size Analyser (Particles dispersed in water and surfactant)*

2. Theory

The relationship between the experimentally determined V of D of unconfined cylindrical charges of high explosives and the charge diameter, d, has been investigated extensively. From the early work of Eyring et al [9] it became apparent that, for ideal explosives, there was an experimentally validated linear relationship between the V of D and the reciprocal of the charge diameter 1/d which took the form:

$$V(d) = D [1-(a / d)] \qquad \text{[Eq. 1]}$$

where **V(d)** is the V of D of a detonating unconfined cylindrical charge of diameter **d**, and **D** and **a**, are curve fitting constants, **D** being the limiting value of the V of D for a charge of infinite diameter and the reaction zone length **a** can be considered a constant characteristic of the explosive formulation.

When the charge diameter approaches the experimentally determined critical diameter, d_c, this equation was quite often seen to fall down especially with high density (>95% TMD) composite or heterogenous high explosives.

To address this problem, Campbell and Engelke [7,10] added a further term to Eq. 1, introducing another curve fitting constant d'_c in order to allow a large amount of V(d) data to be rationalised in mathematical terms. Their equation took the form of Eq. 2,

$$V(d) = D (1-[a / d] - [(a\ d'_c) / (d-d'_c)]) \qquad \text{[Eq. 2]}$$

with d'_c being a calculated diameter, as distinct from the experimentally determined critical diameter.

Whelan and Bocksteiner [3a and b] subsequently discovered that the experimental results from a large number of RDX-driven composite explosives usually exhibited a better fit to a simple elliptical relationship between V(d) and (1/d) than that described in Eqs 1 or 2. This has the form :

$$V(d)^2 = (D^*)^2 (1-[a^*/d]^2) \qquad \text{[Eq. 3]}$$

where, once again, **D*** and **a*** are curve fitting constants, whose values can be obtained from the linear plot of $V(d)^2$ vs $(1/d)^2$.

D* is the extrapolated velocity at $1/d = 0$ and the slope yields $-D^*a^*$. The parameter, a*, could be considered characteristic of the detonating reaction zone for the formulation.
Extending this work, the authors found that a plot of a* vs d_c for various HEs yielded a simple line of best fit of the form:

$$d_c = 2.208\ a^* \qquad \text{[Eq. 4]}$$

which gave very good agreement between the calculated critical diameters and the experimentally obtained figures.

Combining Eq 3 and 4, the "lower threshold velocity" or "cut-off velocity", $V(d_c)$ becomes

$$V (d_c) = 0.892 D \hspace{3cm} [Eq. 5].$$

By implication, $V (d_c)$ is the minimum velocity with which an explosive shock wave can travel and still maintain detonation.

2.1 Calculation of Critical Diameter

The experimental data obtained in this work were fitted to the elliptical relationship between $[V(d)]^2$ and $(1/d)^2$ to determine the limiting value of the V of D (V_∞),for an unconfined cylindrical charge at infinite charge diameter, according to the methods described in [3a and b]. From each plot, the reaction zone length parameter, a^*, characteristic of the explosive, was calculated and this was used to determine the extrapolated critical diameter, d_c, from the simple equation relating these two parameters :

$$d_c = 2.208 \ a^*.$$

3. Experimental

3.1 Charge Preparation

The Composition B samples prepared for the investigation were open cast into 25 mm internal diameter cylindrical moulds and allowed to solidify and cool to room temperature before being pressed from the mould; the unwanted header portions were cut off. The cylinders were then machined to the required diameter (25 mm, 22.5 mm, 20 mm, 17.5 mm, 15 mm, 12.5 mm, 10 mm and 5 mm) and sectioned into 10.00 ± 0.01 mm lengths with a remotely-operated NC lathe.

As was found previously [6], the charges using the milled and boiled [M&B] RDX were the most difficult to cast. Visual inspection of the charge pellets also revealed the [M&B] RDX variants to have slightly more small holes than the recrystallised [R_x] RDX variants. Though great care was used in their preparation the quality of the Composition B charge pellets were assessed as being R_x (best) > B&M 55/45 > B&M 60/40 (poorest). Figure 2 shows an example of the scanning electron micrographs taken of the Composition B samples. The specimen faces have been highly polished and the surface etched with bromoform to highlight the RDX crystals.
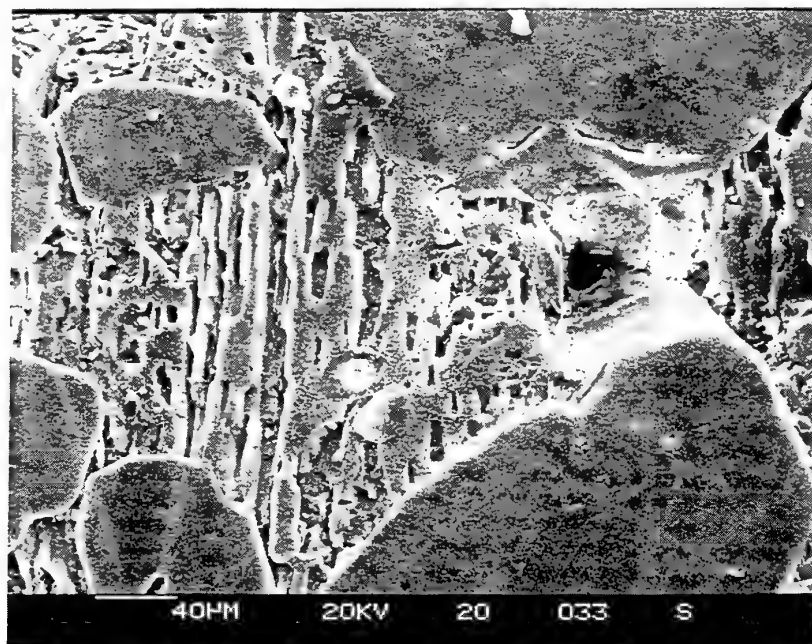
R$_x$-RDX/TNT (60/40) + 1% wax
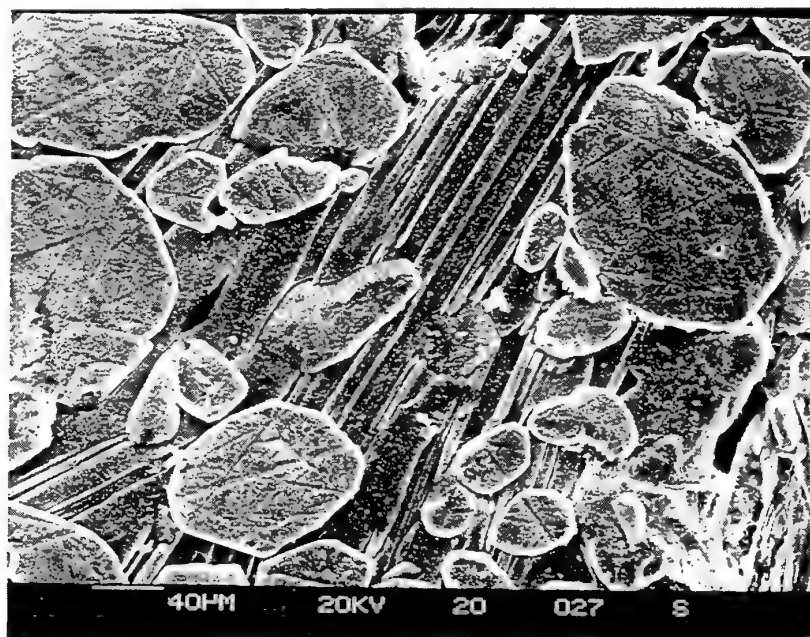
M&B RDX/TNT (55/45) + 1% wax

Figure 2. Scanning electron micrographs taken at ~300X magnification, showing two Australian manufactured Composition B formulations.

3.2 Instrumentation Techniques

The most reliable and accurate method of V of D measurement was found to be an ionisation probe (IP) technique. Measurements were taken over a range of charge diameters from 25 mm to 10 mm in 2.5 mm intervals. Assembly of the probes, however, became progressively more difficult as charge diameters decreased and therefore, subject to error, especially at the smaller diameter.

An alternative technique using high speed photography to follow V of D was used on the smaller diameters ie. 10 mm and 5 mm charges. This technique was employed in an attempt to both validate the probe measurements and to provide data for charges with diameters nearer the expected failure diameter region. Unfortunately, this technique did not give very satisfactory results (see Sect. 4.2).

3.2.1 Ionisation Probe (IP)Technique

Duplicate shots were used for the Composition B samples from 25 mm diameter down to 10 mm diameter in steps of 2.5 mm. Simple and accurate methods of electronically measuring V of D with ionisation switches, also referred to as probes or pins, were described by Campbell et al. back in 1956 [10]. The updated method used at AMRL in this study, involving high speed digital recording and computer techniques, was presented in reference [11] .

Using the assembly shown schematically in Figure 2, the probes were placed at measured intervals between accurately machined cylinders of the cast Composition B formulations. The probes act as open circuit switches which are progressively closed by the passage of the highly ionised detonation front. As each switch closes the electrical pulse that is simultaneously produced was recorded on a digital waveform recorder (Biomation Model 6500) interfaced with a mini computer (Charles River Data System Model MF211) which processed the digitised data and calculated the mean V of D within seconds of the test being conducted. The minicomputer, via a plotter, also performed an annotated plot of the IP voltage pulses and the mean of the V of D.

A block diagram of the measuring system used is shown in Figure 3.

As the size of the diameter of the charge became smaller, the manufacture and assembly of suitably small IPs became progressively more difficult. Measurements on charges of diameters less than 10 mm were not attempted using this technique because the probes would have been bulky and not insignificant in size in relation to the size of the charges.
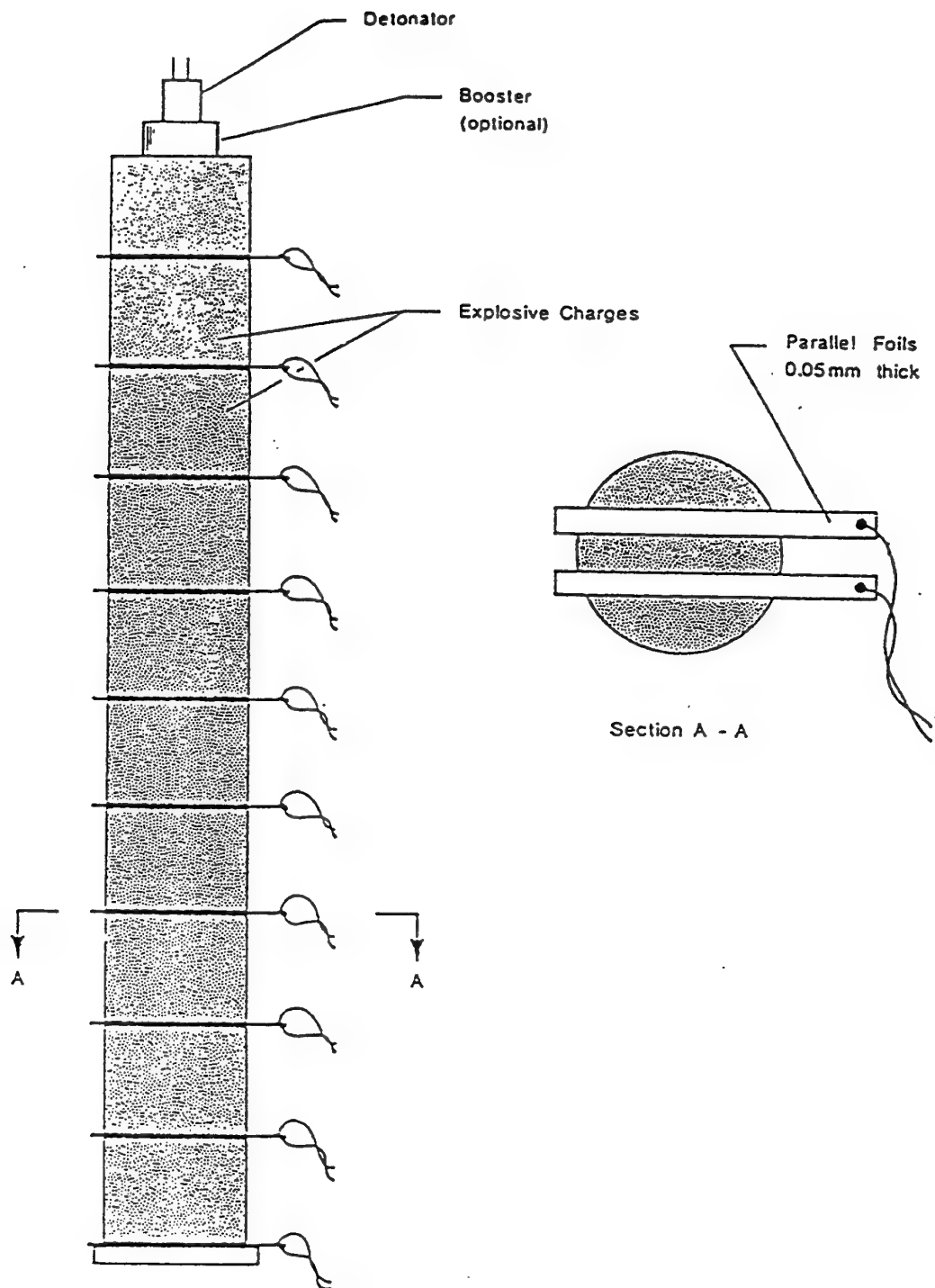
Figure 3. *Parallel foil (Ionisation Probe) V of D assembly. Using machined to size, cast Composition B cylinders.*

3.2.2 Ultra-high speed streak photography (HSP) technique

Reference [12] gives a complete description of this method of V of D measurement.

Figure 4 shows the Composition B pellets in the specially made cardboard jig. The distance between the taut horizontal wires above the detonator and below the end-stop was accurately measured using a Bishop Opto-Scale.

The assembled charge was then set up vertically in the firing chamber and the firing leads connected. A Cordin Mod 330 simultaneous streak and framing camera was used in streak mode with the streak slit being focussed by back projection vertically along the charge and including the horizontal fiducial wires. Using Kodak T-max P3200 film the camera was first run at slow speed with the charge assembly back illuminated thus exposing the silhouette images of the wires and providing fiducial lines along the full length of the film. The film was then rewound, the lights removed and with the camera run at a known high speed the charge was fired. This exposed a continuous displacement/time record of the light output from the detonation front on the same film used for exposure of the fiducial lines, as can be seen in Figures 5 and 6.

The V of D was determined using a Calcomp Mod. 622 digitising tablet, interfaced to a PC, to digitise an enlarged print of the streak record. After allowing for the image magnification and camera writing speed a distance/time plot was obtained. The positions at the start and finish of the streak record which showed that the explosive was under or overdriven from the detonator were excluded from the measurement thus leaving the portion of the streak where stable detonation occurred.

A linear regression performed on the stable detonation points determined the best straight line fit, the gradient of which is the V of D.

4. Results and Comments

4.1 I P Technique

The results of the V of D measurements obtained by the ionisation probe technique and the plotting data can be seen in Table 2.
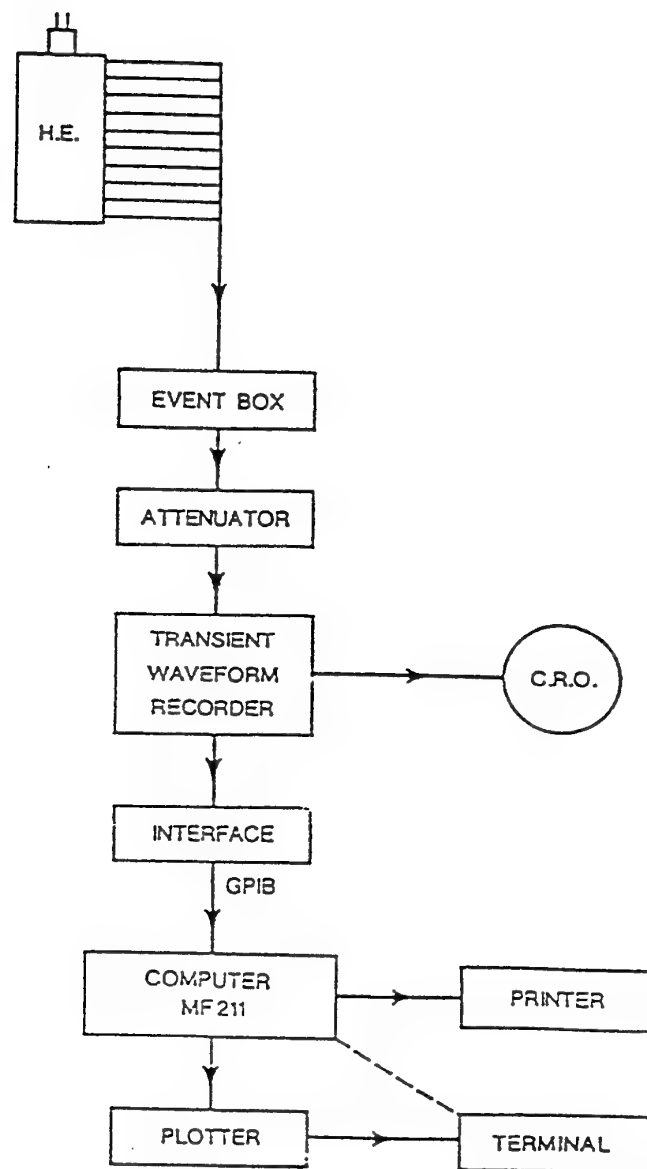
Figure 4. Block diagram of the V of D measuring system for recording the Ionisation Probe signals.
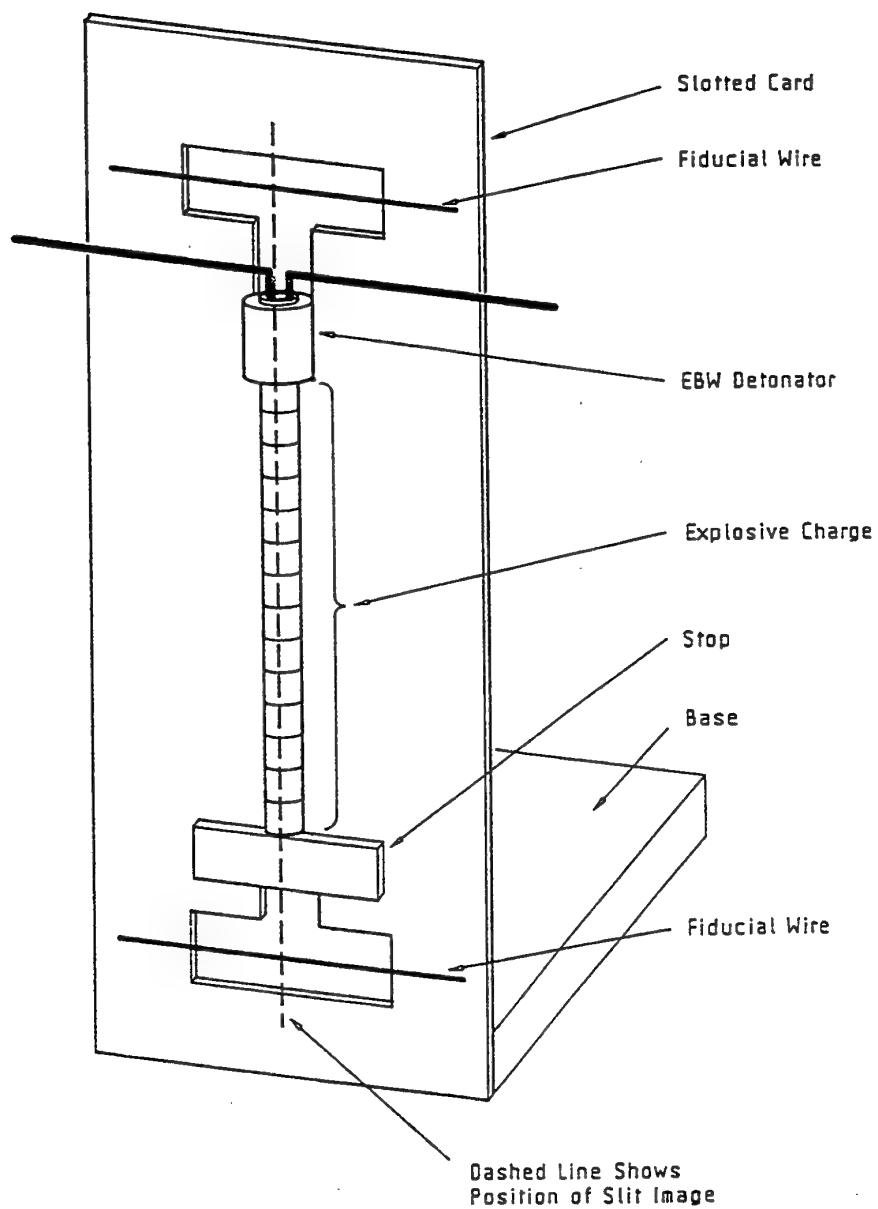
Figure 5.   Schematic diagram of the test assembly used in the High Speed Photographic technique for determining V of D of small diameter cylinders.

Figure 6. Example of HSP technique streak recording, showing result for M&B RDX variant Composition B 10 mm diametrer cylinders.

Figure 7. Illustration of how V of D measurement is calculated. The bright spots that can be seen along the sloping face of the film exposure correspond to the cylinder interfaces.

Table 2. Velocity of Detonation data obtained by Ionisation Probe technique

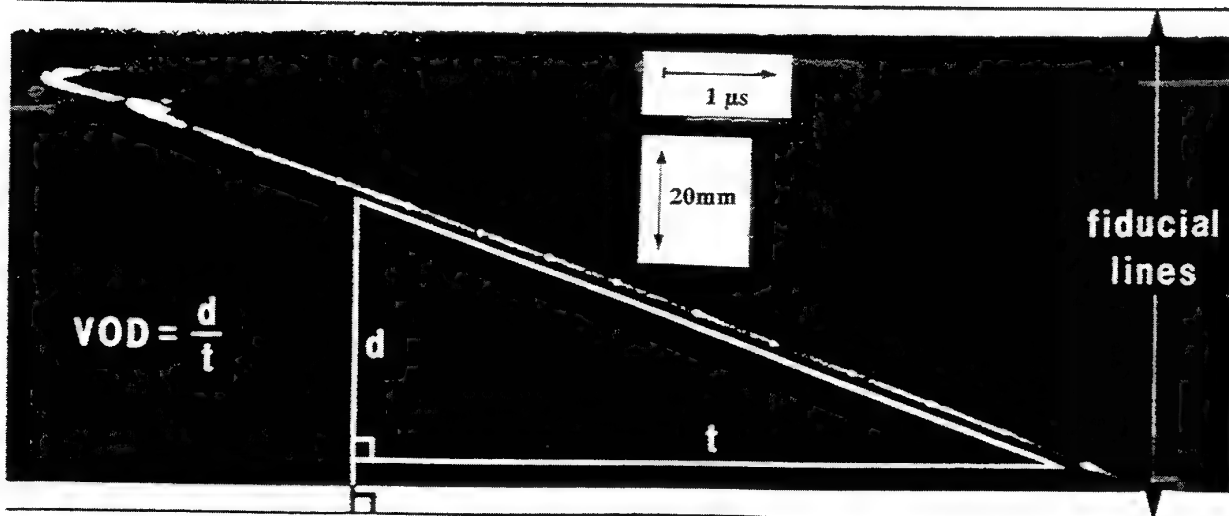| Dia.	1/d,	1/d2	Rx				M&B 1				M&B 2			
d, m	m⁻¹	m⁻²	V(d) m/s	Trend	[V(d)]² (m/s)²	Trend	V(d) m/s	Trend	[V(d)]² (m/s)²	Trend	V(d) m/s	Trend	[V(d)]² (m/s)²	Trend
0.01	100	10000	7222	7253	52157284	52609511	7545	7537	56927025	56809221	7630	7629	58216900	58198622
0.01	100	10000	7210	7253	51984100	52609511	7550	7537	57002500	56809221	7610	7629	57912100	58198622
0.0125	80	6400	7465	7441	55726225	55371164	7580	7583	57456400	57507036	7620	7638	58064400	58340949
0.0125	80	6400	7520	7441	56550400	55371164	7540	7583	56851600	57507036	7660	7638	58675600	58340949
0.015	67	4444	7555	7541	57078025	56871321	7609	7608	57896881	57886096	7675	7643	58905625	58418263
0.015	67	4444	7555	7541	57078025	56871321	7614	7608	57972996	57886096	7650	7643	58522500	58418263
0.0175	57	3265	7605	7601	57836025	57775868	7620	7623	58064400	58114657	7645	7646	58446025	58464880
0.0175	57	3265	7640	7601	58369600	57775868	7645	7623	58446025	58114657	7670	7646	58828900	58464880
0.02	50	2500	7630	7640	58216900	58362955	7650	7633	58522500	58263002	7645	7648	58446025	58495137
0.02	50	2500	7635	7640	58293225	58362955	7620	7633	58064400	58263002	7620	7648	58064400	58495137
0.0225	44	1975	7635	7666	58293225	58765459	7655	7640	58599025	58364707	7665	7650	58752225	58515881
0.0225	44	1975	7630	7666	58216900	58765459	7620	7640	58064400	58364707	7660	7650	58675600	58515881
0.025	40	1600	7665	7685	58752225	59053368	7630	7644	58216900	58437456	7624	7651	58125376	58530719
0.025	40	1600	7653	7685	58568409	59053368	7620	7644	58064400	58437456	7635	7651	58293225	58530719
0.025	40	1600	7717	7685	59552089	59053368	7683	7644	59028489	58437456				
0.025	40	1600					7646	7644	58461316	58437456				

* Trend = The linear least squares fit of the data set

A plot of a typical recorded waveforms and computer readout of the results is shown in Figure 8 .

V of D Record Number : 322A
Operators : Cleeland Wolfson McVay .
Explosive Type : RDX[Recryst.] TNT .
Explosive Composition : 60 / 40 with 1% added wax .
Explosive Fabrication : CAST .
Explosive Density : 1.687 Mg/m³ .

RESULTS
PROBES INSTALLED : 10

DISTANCE [mm]	TIME [μs]
0.00	0.00
10.11	1.40
20.23	2.80
30.27	4.20
40.41	5.62
50.46	7.00
60.48	8.40
70.59	9.78
80.63	11.16
90.75	12.54

Velocity of Detonation :   7225 m/s
Standard Deviation   :   9 m/s

RECORDING DEVICE :   HP 54200A
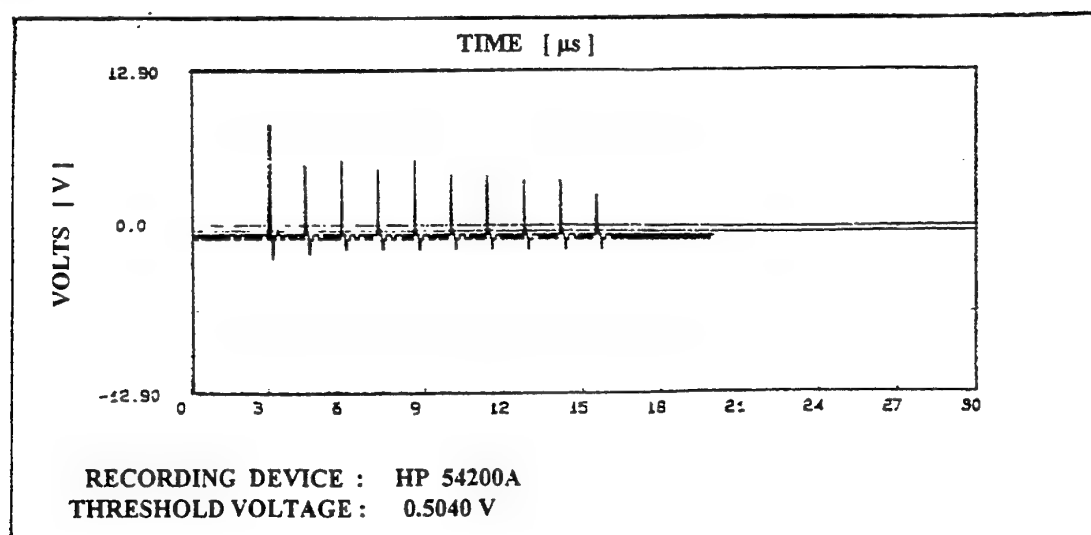THRESHOLD VOLTAGE :   0.5040 V

Figure 8.   Typical printout for IP technique V of D software.

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By plotting all the experimental V(d)-vs-d results from Table 2 in the form described by both the linear dependency, Eq. 2, shown in Figure 9, and the elliptical dependency, Eq. 3, shown in Figure 10, for each of the Composition B formulations, it can be seen that the elliptical relationship gives a slightly better fit to the data and predicts the V(d) at large charge diameters to be less than those expected on the basis of Eqs.1&2. A statistical analysis of the data predictions shows an improvement in the confidence level [linear least squares (LLSQ) coefficient of determination] of the elliptical relationship over the linear relationship. See Table 3.

This was not as pronounced an improvement as had been observed in previous studies [3a and b] however it again validated Whelan's elliptical relationship theory for heterogenous RDX containing explosives.

It has been shown elsewhere [3a and b] that for many heterogenous RDX-containing explosives, Eq. 3 usually gives a more reliable estimate of the limiting values for the V of D at infinite charge diameter, (D*); this was true for the US produced Composition B [8, 13] and is expected to apply here. The results of both the work described here and of the US work are listed in Table 3.
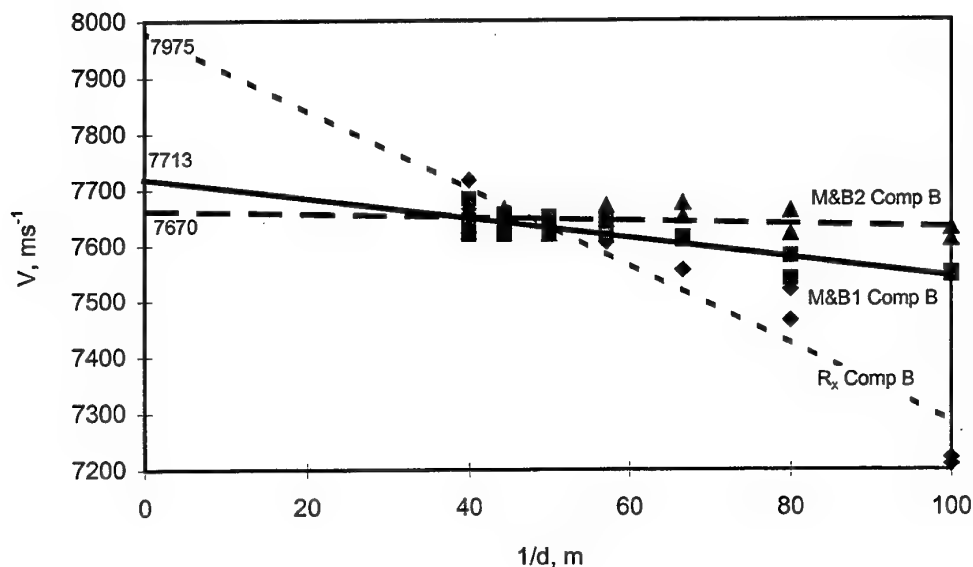

Figure 9. Plot of [1/d] vs [V] for the various Composition B formulations
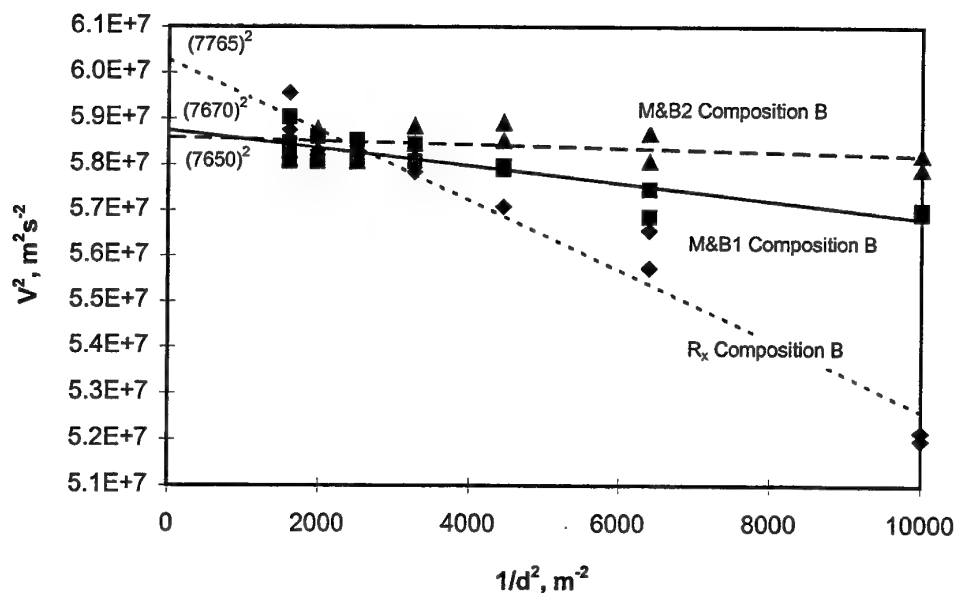
Figure 10. Plot of [1/d]² vs [V(d)]² for the various Composition B formulations

Table 3. Analysis of the empirical relationship between the V of D at Infinite Charge diameter [D] and the reaction zone length parameter a* for the data from Table 2. US data is included for comparison.

RDX type	Density Mg/m³	No of points	D ms⁻¹ [Eyring] [7]	a mm linear	r² ☺	D* ms⁻¹ [Whelan] [1]	a* mm elliptical	r² ☺
Rₓ	1.66	13	7883	0.529	0.908	7717	2.987	0.925
averaged		7	7847	0.555	0.951	7723	3.04	0.960
M&B 1	1.66	15	7714	0.210	0.788	7664	1.745	0.801
averaged		7	7706	0.190	0.965	7659	1.643	0.957
M&B 2	1.68	14	7666	0.0432	0.092	7658	0.866	0.136
averaged		7	7666	0.043	0.127	7658	0.863	0.187

Footnote : US data for Composition B for comparison

Malin [13]	RDX,63%; TNT,37%; Slow Melt; >80% by mass RDX <400 micron							
	1.70	12	7964	0.26	0.963	7865	1.517	0.997
Gibbs &	RDX 59.5 %,TNT 39.5 %, Wax 1 % > 90 % by mass RDX < 300 micron							
Popolato [8]	1.70	18	8022	0.340	0.888	7895	1.673	0.981

☺ r² = LLSQ coefficient of determination

The large scatter for the Composition B formulation designated M&B2, see Table 3 and Figure 10, indicates that the critical diameter of the formulation is very low and that, even for charges with very small diameters, the V(d) is close to D*. Hence there is a relative lack of discrimination between the linear and the elliptical V(d) dependencies for this formulation . This was not the case for the M&B1, nor for the underwater high explosive Composition H6 [14], which was examined in a previous experiment of this type, where the critical diameters were significantly larger.

4.2 H S P Technique

The results of the High Speed Photographic[HSP] Technique V(d) measurement are shown in Table 4. The first two shots of the R_X series failed to transfer detonation from the booster. A larger booster was then used for the remaining shots. Using this technique the results could not match the consistency of the IP technique. As the V(d) results of duplicate shots could not be used to validate each other the technique was discontinued after 12 shots.

Table 4. Results of V of D calculations for Composition B, from measurements of the HSP film record.

RDX type	Shot No.	Dia. mm	Result D or ND	V(d) plus Comments		Comparison with Av. IP result
R_x	1	10	ND	Booster size thought to have been insufficient		
"	2	10	ND	As above		
"	3	10	D	Larger booster used, V(d) est. 7556m/s	#	7216
"	4	10	D	As above,V(d) est. 7877m/s	#	7216
"	5	5	ND	No detonation even with large booster		
"	6	5	ND	As above		
	Shot No.	Dia. mm	Result D or ND	V of D plus Comments		
M&B1	1	10	D	No film result		
"	2	10	D	V of D est. 7960m/s, #		7547
"	3	10	D	V of D est. 8134m/s, #		"
"	4	10	D	V of D est. 7930m/s, #		"
"	5	5	D	V of D est. 7683m/s, #		"
"	6	5	D	V of D est. 7916m/s, #		"

D = DETONATION

ND = NON DETONATION

= Duplicate shots failed to validate result

Spear and Wolfson [12] had noted that the HSP technique appeared to give consistently higher V of D results than the IP method. A variation in image sharpness across the film and a variation in magnification across the film of about 9% from edge to edge was reported.

The HSP V of D measurements in Table 4 appear to be in the order of approximately 400 m/s greater than the corresponding charges in Table 1, however, this still did not account for why some results varied for duplicate charges of the same composition, density and diameter. In shots 5 and 6 it was shown that even when a large booster was used the 5mm diameter R_x charges could not be made to detonate. Though this small number of shots is not sufficient to be conclusive it strongly suggests the failure may be due to the charges being below the d_c.

The density of each of the (approximately) 500 individual pellets used in the tests were measured and the average densities for each composition and charge diameter are given (Table 5).

Table 5. *Averaged Composition B pellet densities used in the High Speed Photographic [HSP] technique for V of D determination .*

Pellet type	B&M 1 (55/45)	B&M 2 (60/40)	R_x 60/40
Charge diameter [mm]	Av. Density [Mg/m³]	Av. Density [Mg/m³]	Av. Density [Mg/m³]
25	1.671	1.665	1.681
22.5	1.670	1.669	1.679
20	1.663	1.662	1.683
17.5	1.663	1.661	1.683
15	1.666	1.672	1.682
12.5	1.663	1.663	1.684
10	1.657	1.668	1.681

Comparing the 60/40 Composition B mixes, the density measured for the R_x variant pellets was fairly consistent, being approximately 0.02 Mg/m³ denser than that of the M&B. Given the previously mentioned problem of mixing the B&M 60/40 composition, this difference in density can be attributed most probably to the greater inclusion of minute air bubbles in this latter material. At these density variations the detonation process would not be expected to have altered significantly, however, the proposed occlusion of minute voids would affect the initiation process and thus the growth to detonation.

The densities of the M&B 55/45 and 60/40 pellets were very similar. It was thought that the 60/40, with its greater percentage of the higher density RDX and lesser percentage of the lower density TNT, would have had a slightly higher average

density than the 55/45. That this was not the case, again suggests the entrapment in the cast pellets of the 60/40 Composition B of minute air bubbles. As mentioned above this could be expected to increase shock sensitivity.

Table 6. Best estimates of the Critical Diameters and Cut-off Velocities for the Various Composition B formulations studied in this Report.

Composition	Critical Diameter, mm	Cut-Off Velocity, V (d_c) $m\ s^{-1}$
R_X, [R_x-RDX / TNT (60/40) + 1% wax] Note: RDX Grade A,	6.7	6883
MB1, [M&B-RDX / TNT (60/40) + 1% wax] Note: RDX Grade B,	1.9	6836
MB2, [M&B-RDX / TNT (55/45) + 1% wax] Note: RDX Grade B,	3.6	6831
Composition B from US Sources Malin [13] Gibbs and Popolato [8] Campbell and Engelke [7,10] TNT/RDX/Wax (36/63/1) TNT/RDX/Wax (39.5/59.5/1)	 3.3 3.7 3.9 4.3	 7016 7042 7010 7156

In Table 6, the critical diameter (which is the minimum diameter for stable detonation of the unconfined cylinders) and the cut-off velocity (which is the V of D at d_c) are listed for each formulation . These were calculated using Eqs 4 and 5 .

5. Discussion

On noting the significant difference in d_c between the fine and coarse (same formulation) RDX in the types of Composition B, the different shock sensitivity test results in the variants were also examined. In previous work from this laboratory, it was found that R_x - RDX based Composition B was considerably less sensitive to shock initiation than its M&B counterpart [1,2] . Because of the difference between the shock initiation build-up, with its ignition and growth phases, and the type of reactions at the detonation front there can be no correlation between the shock sensitivity and the V of D of the samples tested. However, the empirical nature of the SSGT, with its small

diameter donor, appears to exhibit a trend of increased sensitivity with decrease in d_c. See Table 7.

The SSGT [1] and LSGT [2], compare the response of an explosive to high impulse/short duration shocks. In the SSGT the donor charge, Scale 1, uses a single exploding bridgewire detonator (EBW) to initiate the detonation. When this was not powerful enough, as was the case with the R_x Composition B samples, a Scale 2 donor, boosted by a pressed PETN pellet was used.

That it was found necessary to use Scale 2 to initiate the R_x variant charges yet the M&B charges were each adequately initiated using Scale 1 indicates qualitatively that those charges formulated with R_x RDX are less sensitive than those formulated with the M&B RDX, to this form of initiation. In the LSGT where the donor charge is 50.8 mm in diameter the gap difference between the Composition B samples tested is less apparent.

Table 7 below compares the SSGT and LSGT sensitivities of the two Composition B variants (1 and 2). For both gap tests, the higher the gap the greater the sensitivity.

Table 7. SSGT and LSGT Results for Composition B Charges

Composition B	d_c mm	SSGT Gap for 50% detonation probability		LSGT	
		Scale 1	Scale 2	M 50% (mm)	Pressure GPa
Grade A RDX [R_x]/TNT/wax (60/ 40 / 1) ρ = 1.67 Mg/m³	6.7	no detonation	19.7	47.6	2.5
Grade B RDX [M&B1]/TNT/Wax (55 / 45 / 1) ρ = 1.67 Mg/m³	3.6	14.3	34.2	51.1	2.0
Grade B RDX [M&B2]/TNT/Wax (60 / 40 / 1) ρ = 1.66 Mg/m³	1.9	not tested	40.6	not tested	not tested

A similar trend of increased shock sensitivity with decrease in RDX particle size was also found for projectile impact shock wave initiation. Table 8 below details the results. In these experiments a 12.7 mm diameter projectile was fired at large diameter cylinders of both 60/40/1 fine and coarse RDX Composition B variants and the

threshold velocity for initiation of detonation was found [16]. The shock wave delivered to the target in this test differs from the gap tests in that it has a lower impulse and a longer duration.

Table 8. *Comparison of critical diameter (d_c) with Impact shock Critical Velocity (V_c) results.*

Composition B variant	d_c mm	V_c (experimental) ms⁻¹ [17]	No. of shots	*L95% ms⁻¹
R_x	6.7	970	7	44
M&B 2	1.9	860	9	4

- L95% Bruceton confidence limit

Note the projectile diameter (in the V_c test) and the sample diameter (in the d_c test) were both greater than the d_c results found.

A possible explanation of what may be occurring is as follows:

When the bare flat surface of the explosive receives an impact from a flat-ended cylindrical projectile, or from a booster, the explosive surface is subjected, at the moment of impact, to an area under shock which is related to the diameter of the projectile. The shock generated travels into the explosive and is affected by side rarefaction. If a shock-to-detonation transition has not occurred before the shock front is reduced in diameter below the value of the critical diameter of the explosive and the pressure is too low, then a detonation cannot result. The smaller the critical diameter, the longer the time available for the shock wave to initiate the detonation reaction and the further into the explosive sample the shock will be able to travel. If this is correct the R_x variant could be expected to have a V_c significantly higher than its M&B counterpart, which is what was found. However, not forgetting the slightly lower densities of M&B 2 samples compared to the R_x (as per Table 5), it could also be that the increase in shock sensitivity is caused by micro encapsulated voidage.

Many early reports attempted to attribute changes in V_c to single factors such as particle size, the distribution of the particles and crystal morphology of the RDX component. Looking at it from a different perspective it may be that the d_c (or a*) could be considered as a measure of the combination of these three properties that results in the V_c change.

Several authors, including Campbell [17] and Scott [18] had noted what appeared to be different energies for initiation of fine and coarse samples of both TNT and RDX. Little information could be found on whether this still occurred after their blending and casting into Composition B. Price [19] suggested that it might be that the fine and coarse materials represent a single sample capable of undergoing two different reactions requiring different activation energies. That the d_c and V_c results varied so greatly for

the fine (M&B2) and the coarse (R_x) supports Price's postulation of differing activation energies.

The idea to try to link the properties particle-size and shock sensitivity with d_c, which at first thoughts seemed reasonable, was found to be complicated by several other unresolved properties. These properties, described by Campbell et al [17], included time-to-ignition, ignition-and-growth phenomena and time-of-buildup of the chemical reaction. It would appear that a clear understanding of what happens at the boundary where detonation either succeeds or fails, such as critical shocks and projectile interactions, will be beyond the efforts of researchers for a few more years.

Though the HSP V of D measurements were considered inconclusive the detonation-non detonation results for the 5 mm charge diameters agree with the findings of the IP results. That is, the R_x Composition B charge columns could not be made to detonate even with an oversized booster, proving that its d_c must be between 5mm and the 10 mm at which it did detonate. That the M&B 55/45 Composition B had no trouble detonating from the smaller booster, proved its d_c must be below 5 mm.

In a similar d_c study of the Australian manufactured underwater explosive Composition H6 [16], comparisons were made with its US counterpart. The Australian H6, made with the smaller grain size M&B RDX crystals had a significantly smaller d_c than the US H6, where larger grained RDX crystals were used. This appears to compliment the findings in this report with respect to Australian Composition B in that again the particle size of the RDX crystals appears to be the controlling factor in determining the d_c.

6. Conclusions

The critical diameters of the three current casting formulations of Australian-manufactured high explosive bomb filling Composition B have been evaluated. Both varieties made with the fine M&B, RDX were found to have significantly smaller d_cs than their coarse R_x, RDX 60/40/1 (RDX/TNT/Wax) counterpart. Using the elliptical relationship formula on V of D data obtained using an IP technique, the following predictions could be made.

Parameter	Symbol	Composition B RDX type		
		Grade A 60/40/1	Grade B 60/40/1	Grade B 55/45/1
V of D at infinite charge diameter	D_∞	7723 m/s	7658 m/s	7659 m/s
cut-off velocity	$V(d_c)$	6883 m/s	6836 m/s	6831 m/s
reaction zone length	a^*	3.04 mm	0.86	1.64
critical diameter	d_c	6.7 mm	1.9 mm	3.6 mm

A second instrumentation technique using HSP could only manage to confirm that the R_x RDX Composition B d_c was greater than 5 mm and the M&B variety was less than 5 mm.

Insufficient information was available to explain the observed trend, for the Composition B variants, that both d_c and shock sensitivity decreased with RDX particle size.

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19. ABSTRACT

Composition B is a widely used high explosive main charge filling for general purpose bombs. In Australia it is manufactured from either RDX (Grade A or Grade B)/TNT 60/40 with 1% wax, or RDX (Grade B)/TNT 55/45 with 1% wax.

In weapon applications computational models require experimental data to determine certain specific output parameters of Composition B to predict air-blast and fragmentation scenarios. To this end, the critical diameter, which is the minimum diameter which will sustain a stable detonation, and the limiting value of the velocity of detonation at infinite charge diameter $D(\infty)$, were determined for unconfined cylinders of each Composition B type. An ionisation probe technique was used to measure the velocity of detonation (V of D) of the samples over a range of charge diameters (d).

The data thus obtained was fitted to an elliptical V (d) relationship to obtain the critical detonation parameters below:

RESULT				
Parameter	Symbol	Composition B RDX type		
		Grade A 60/40/1	Grade B 60/40/1	Grade B 55/45/1
V of D at infinite charge diameter	D_∞	7723 m/s	7658m/s	7659 m/s
cut-off velocity	$V(d_c)$	6883 m/s	6836 m/s	6831 m/s
reaction zone length	a^*	3.04 mm	0.86	1.64
critical diameter	d_c	6.7 mm	1.9 mm	3.6 mm

Although separate experiments suggested a trend of shock sensitivity decreasing with RDX particle size insufficient data was available to investigate the observations.